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SPONSORED PROJECT INITIATION

Date: October 4, 1977

Project Title: Excitation and Ionization of Ions by Electron Impact

Project No: E-21-613

Project Director: Dr. Robert K. Feeney

Sponsor: U. S. Energy Research and Development Administration; Oak Ridge Operations

Agreement Period: From 9/1/77 Until 8/31/78

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SPONSORED PROJECT TERMINATION

Date: 12/4/78

Project Title: Excitation and Ionization of Ions by Electron Impact

Project No: E-21-613

Project Director: Dr. Robert K. Feeney

Sponsor: US Energy Research & Development Admin./Oak Ridge Operations

Effective Termination Date: 8/31/78

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- _ Final Invoice and Closing Documents
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- _ Final Report of Inventions
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REPORT NO. ORO–3027-43

Technical Progress Report

Project No. E-21-613

Covering the Period
September 1, 1977 to May 31, 1978

THE EXCITATION AND IONIZATION OF IONS BY ELECTRON IMPACT

By R. K. Feeney
D. W. Hughes
G. B. Hoak
D. C. Priester
W. E. Sayle

Contract No. EY–76–S–05–3027

Department of Energy
Oak Ridge, Tennessee

31 May

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL ENGINEERING
ATLANTA, GEORGIA 30332

REPORT NO. ORO-3027-43

PROJECT NO. E-21-613

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U.S. Department of Energy

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TABLE OF CONTENTS

ABSTRACT

This effort is devoted to the measurement of electron impact collision processes of importance in controlled thermonuclear research. Electron impact single and multiple ionization of ions and charge exchange processes are being studied. A program to develop ion sources for future collision experiments is also included.

Preliminary measurements of the electron impact triple and quadruple ionization cross sections of Rb^+ ions have been completed. Measurements were made over the range of electron energies from the respective thresholds to 1000 eV. Peak cross sections were found to be 1.8×10^{-18} cm^2 and 4.2×10^{-19} cm^2 for triple and quadruple ionization, respectively. The data were obtained with a "universal" crossed beam apparatus operating with modulated beams.

A hollow-cathode discharge type ion source and associated m/e analyzer has been constructed. This source module is compatible with the ionization apparatus and will be used to make measurements of electron impact ionization cross sections of singly charged metallic ions.

A charge exchange apparatus suitable for the measurement of electron capture and stripping cross sections of selected singly charged metallic ions and neutrals is being designed. This apparatus will be employed with the hollow-cathode ion source module.

A Penning Ion Gauge (PIG) type ion source of multiply charge ions is in continuing development. This source is of laboratory size and is designed to be used with all existing and planned collision experiments. This effort is directed toward future applications and is proceeding with low priority.

SECTION I

DISCUSSION OF PROGRESS

This summary covers progress made during the current period of September 1, 1977 to May 31, 1978. The general goal of this work is the measurement of cross sections for electron impact ionization and excitation of ions and for other collision processes that are of importance in the near-and far-term CTR program. The specific programs involved in the research effort as extracted from the currently active proposal are: (a) measurements of the absolute cross sections for electron impact triple and quadruple ionization of Rb^+, Cs^+, and Tl^+ ions; (b) measurements of the absolute cross sections for the electron impact single and double ionization of Cu, Mo, Au ions; (c) measurements of electron capture and stripping cross sections of Cu, Ni, Au, and Mo singly-charged ions and neutrals, respectively; and (d) continuation of ion source development leading to a laboratory size source of multiply-charged metallic ions.

Progress toward the above goals is being made at what is considered to be a satisfactory rate. Preliminary measurements of the electron impact triple and quadruple ionization cross sections of Rb^+ ions have been completed. The existing apparatus was converted into a "universal" apparatus which can sequentially measure double and higher ionization processes. The ion source required for electron impact ionization cross section measurements of metallic ions is being tested. Most of the current contract period has been utilized to construct the necessary ion source power supplies and vacuum equipment. Testing was initiated about May 15, 1978 and is expected to be completed in another month. Most of the work done on the charge exchange experiment has involved design or component procurement. Since the metallic ion source is needed for this experiment, it is sufficient to continue development so that the experiment is operational when the ionization work is completed. Work on the PIG type ion source is continuing with a low priority. A redesign of the ion source body has been undertaken.

The following section summarizes the progress made and problems encountered in each of the above research programs. Details of the experimental results and discussions of apparatus are presented in appropriate appendices.

Multiple Ionization of Ions

Preliminary measurements of the electron impact triple and quadruple ionization cross sections of Rb^{+} ions have been completed over the range of electron energies from the threshold values to approximately 1000 eV. This work was undertaken to provide data for use in the calibration of ion beam probes. Such probes can measure plasma density, space potential, charge and current density, electric and magnetic fields and electron temperature.[1-7] Most of the ion beam probes have relied upon the use of singly charged probe-ions, i.e., a single ionization event. Electron temperature measurements are usually made by simultaneously injecting two species of ions into the plasma. If the cross section of each ion has a different variation with electron energy, the ratio of the two is independent of the electron density and is a unique function of electron temperature. In certain situations, it is desirable to use the simultaneous ionization of a single probe species to different charge states. The advantage of this technique is the higher electron temperature that can be measured because of the greater threshold energy for multiple ionization. This approach appears to be promising on EBT where ionization states up to fifth have been observed.[8]

Because of the lack of reliable theoretical estimates, measured cross sections are essential for valid beam probe diagnostics. Our last Progress Report presented results for the double ionization of the alkali ions.[9] The present effort was undertaken to measure the electron impact triple and quadruple ionization cross sections of Rb^{+}, Cs^{+}, and Tl^{+} ions. These results will continue to be disseminated to the using community as rapidly as they are obtained.

The electron impact multiple ionization cross sections of Rb^{+}, Cs^{+}, and Tl^+ ions are currently being determined with a modified form of the apparatus used in our double ionization work.[10] The experiment was changed to allow sequential measurement of double and higher ionization processes. Details of the apparatus and a summary of the present experimental results are given in Appendix I.

Ionization of Metallic Ions

The measurements of the metallic ions were undertaken because of engineering constraints on high energy ion beam probes. In order to take advantage of a tandem Van de Graaff generator as the energy source for the high energy ion beam probes, it is necessary to initially produce negative ions. The negative ions are then stripped while at high potential yielding a positively charged ion beam of twice the acceleration energy. The necessary negative ions are easily made from metallic species, hence the requirement for ionization cross sections of representative metallic ions.

Alkali ions are ideal for use as probe-ions. They have the highest second ionization energy of any atomic configuration which leads to enhanced temperature measurement capability. Unfortunately, it is difficult to produce negatively charged heavy alkali ions, but negative ions are easily made from some other metallic elements.[11-13] Any metal ions selected for high energy ion beam probes should have parameters similar to those of the alkali metals. The logical candidates are therefore those metals near the alkalies in the periodic table.

The alkaline earth metals cannot be used because of their low electron affinity. Of the remaining metals, Cu, Au, and Mo appear to offer the greatest potential as probe-ions. Accordingly, the present research program was developed to measure the electron single and double ionization cross sections of these ions.

Measurements will be made with the same apparatus used for the alkali work. However, since the metallic ions cannot be made with a thermionic type ion source, it was necessary to construct a suitable ion source and beam handling system. The PIG source was not employed because it consumes a great amount of power and has a short operational lifetime. The multiply-charged output of the PIG was not required. A commercial Danfysik Model 911A ion source module and associated power supplies was designed and constructed. Differential pumping was incorporated so that the source module could connect to the ionization apparatus. The same source module will be used with the charge exchange experiment. Details of the system design and preliminary performance data for the ion source are presented in Appendix II.

Electron Stripping and Capture Cross Sections

Large continuously operating neutral beam injectors will probably be required for future experimental and power producing fusion reactors. It is important that these neutral injectors not introduce heavy impurities into the plasma, since significant quantities of such heavy impurities could appreciably increase the energy loss from the plasma.[14-19]

Neutral heavy atoms are produced in the injectors by sputtering and evaporation from the focusing grid structures. These neutral atoms may be ionized by electron impact. If ionization occurs in a region of non-zero electric field, the ions will be accelerated down the injector into the neutralizer cell. The energy of these ions will depend upon the potential at the point in the injector where they were created. If these ions are neutralized in the gas cell, they may enter the plasma region and be trapped. It is important to know the electron capture cross sections of these ions so that the likelihood of their being neutralized can be assessed.

Heavy impurities are trapped in the plasma when the neutral atoms become stripped or impact ionized. Charge exchange (stripping) is the dominant trapping mechanism for the relatively slow heavy atoms when the electron temperature is greater than a few hundred eV.

Thus the important collision process in trapping the neutral heavy impurities is electron stripping. Cross sections for this process are required to evaluate deposition of impurity atoms from the neutral beam system into the plasma.

This portion of the current research program was designed to obtain these required stripping and electron capture cross sections. The electron capture and stripping cross sections of Cu, Ni, Au, and Mo singly charged ions and neutrals, respectively, are to be measured. The measurements will be accomplished with an apparatus somewhat similar to that used by Barnett and his co-workers.[20-24]

The ion source used with this experiment will be the hollow cathode source discussed in the previous section. All of our collision experiments are being designed to accomodate any of the several available ion sources (PIG source, hollow cathode source and thermionic source).

Most of the work during this contract period has been devoted to design of the experiment and to equipment acquisition. All major equipment is now available. The necessary 100 kV isolation transformer was recently procured at no cost to this project. Details of the experimental apparatus are presented in Appendix III.

Ion Source Development

As discussed in the previous section, heavy elements from the walls or neutral beam injectors can enter the plasma of a CTR machine. If partially ionized, these high-Z elements become very effective line radiation emitters. Such radiation greatly increases energy loss from the plasma. The validity of theoretical calculations of energy loss depends upon the accuracy of the various collision cross sections.

The most fundamental requirement that must be satisfied before collision cross sections can be measured is the production of adequate currents of the desired ion.

A PIG-type ion source has been under development for several contract periods. The source was originally intended to produce multiply charged atmospheric ions. Since Barnett's group at ORNL was engaged in collision measurements of atmospheric ions, the direction of our work was changed to avoid potential conflict with this effort. It was decided to convert the PIG source to the production of multiply-charged metallic ions. In addition, operating experience with the source had revealed several design deficiencies For example, it was much too difficult to replace expended cathodes and the extractor was also very susceptible to breakdown.

The decision was made to redesign the source, incorporating those changes dictated by experience as well as the metallic ion capability. This redesign has been proceeding during the present contract period. Details of the various problems and the design are presented in Appendix IV.

SECTION II

PUBLICATIONS

The publication listed below was prepared or published during the current reporting period based upon completed research. Conference presentations are not listed.

1. Title: "Absolute Experimental Cross Sections for the Electron Impact Ionization of Rb^+ Ions"

   Authors: R. K. Feeney, William E. Sayle, II, and T. F. Divine

   Status: Accepted for publication in Physical Review (July 1978).

   Support: ERDA 75%, Georgia Tech 25%

APPENDIX I

MULTIPLE IONIZATION OF IONS

The electron input double, triple and quadruple ionization cross sections for Rb^+ have been measured as a function of incident electron energy from below threshold to approximately 1000 eV. These results, together with a discussion of the experimental apparatus and techniques, are presented in this appendix. Some comparisons with available theoretical calculations are also given.

The experimental method involves the use of a crossed beam apparatus in which approximately monoenergetic beams of ions and electrons are caused to intersect at right angles in a well-defined collision region. The crossed beam technique has now become a well-established tool for the study of charged-particle--charged-particle collision processes. Several reviews that discuss the advantages and difficulties inherent in crossed beam experiments have been written and most of the early work utilizing this method critically evaluated.[25-29] Accordingly, with the availability of such a complete body of reference material, a general discussion of the experimental technique will not be given here; however, those unique problems associated with the present experiment are discussed in appropriate sections.

A schematic diagram of the experimental apparatus is given in Figure A-1 and a plan view photograph is shown in Figure A-2. Singly charged ions are produced by a thermionic-type ion source and pass through several focusing, collimating and deflecting structures before entering the interaction region. A rectangular electron beam intersects the ion beam in the collision volume.

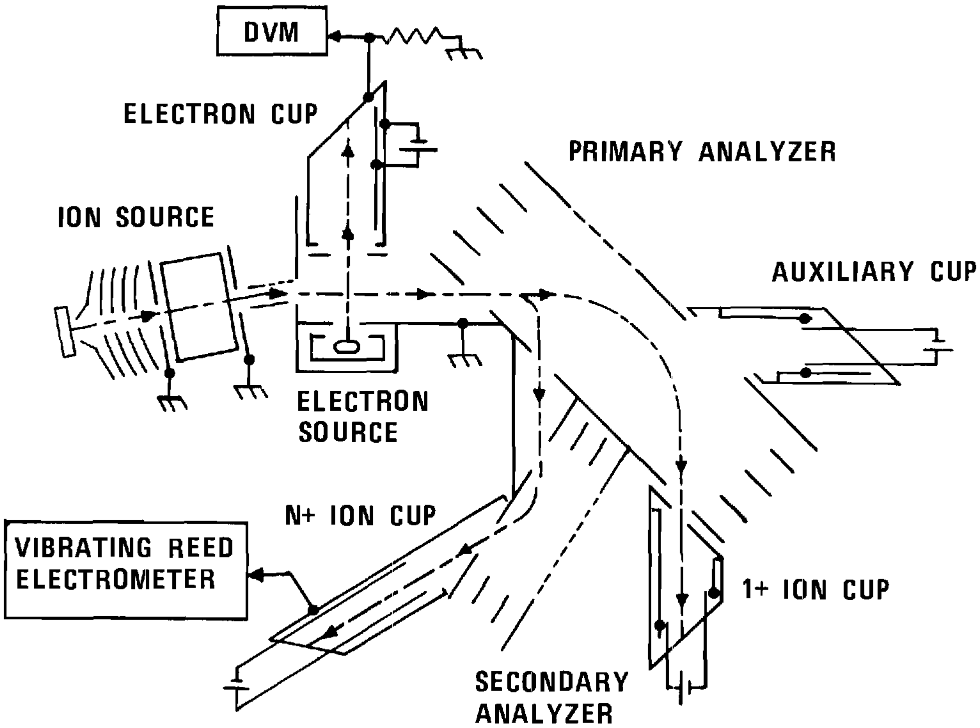

Figure A-1. Schematic Diagram of the Ionization Apparatus.

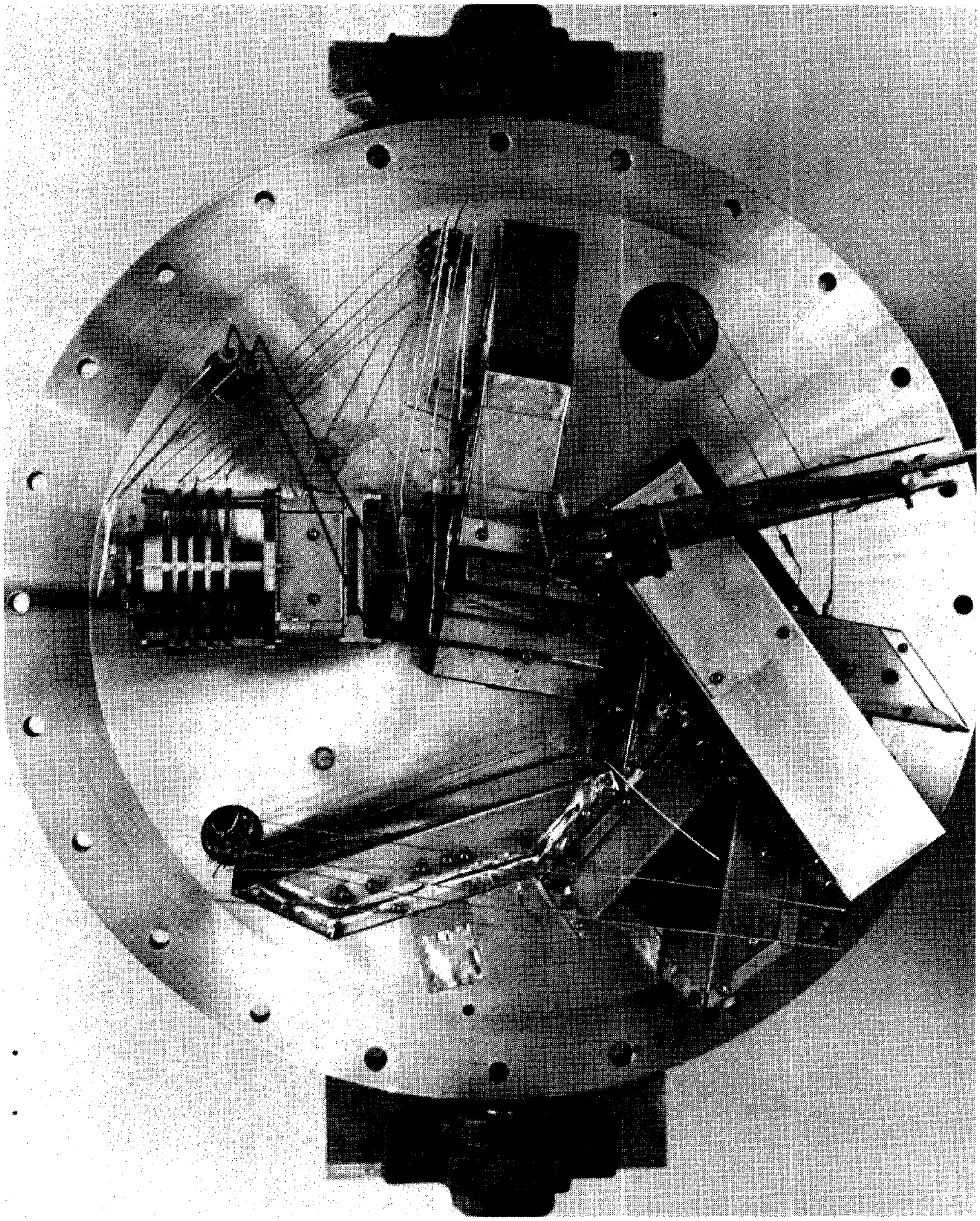

Figure A-2. Plan View Photograph of the Ionization Apparatus.

Just prior to entering the interaction region, the two beams can be made to pass through a scanner which determines their spatial profiles. This scanner is driven from outside the vacuum chamber by a stepping motor sequenced by a preset counter. After undergoing collisions with the electrons in the interaction region, the ion beam, which now contains several charge states, passes into the large parallel plate primary electrostatic analyzer. Here the singly- and multiply-charged beam components undergo initial separation.

The singly-charged ion beam is diverted into a Faraday cup while the multiply-charged ion beam passes into the secondary electrostatic analyzer. This analyzer removes slow ions produced by the singly charged ion beam ionizing or charge exchanging with the background gas. Such slow ions are deflected through the primary analyzer, but do not have the correct energy to traverse the secondary analyzer. Both the primary and secondary analyzers employ mesh-type back plates to reduce the chance that reflected stray electrons will be collected. Guard rings are incorporated in both analyzers for improved uniformity of the electric fields.

Upon exiting the secondary analyzer, the multiply charged ion beam is collected by a Faraday cup. This cup has a secondary electron suppressor placed in front of it. In addition, permanent magnets provide a magnetic field perpendicular to the axis of the cup. This field provides additional secondary electron suppression and also helps to keep out scattered background electrons.

Not shown in the diagram, but appearing in the photograph, is a movable Faraday cup which can be lowered into the path of the ion beam prior to its entering the interaction region. This cup facilitates comparison of the ion beam entering the primary electrostatic analyzer with those beams emerging from both the primary and secondary analyzers. Such a feature has been very useful in preventing unusual focusing conditions which could result in some ion beam loss prior to its entering the signal detection region.

An auxiliary cup has been positioned behind an opening in the rear shield of the primary analyzer. This cup collects all of the singly-charged (ion) beam for a wide range of analyzer operating parameters. Such an arrangement allows the deflection of multiply-charged products into the signal detection cup while continuously monitoring the primary beam current in the auxiliary cup. This capability enables the cross section for all electron impact impact ionization processes of interest to be determined without mechanically altering the experimental apparatus. The creation of such a "universal" experiment has considerably reduced the amount of time required to measure the various ionization cross sections for a particular ion species.

An additional aid to the handling of ionization data from the experiment has been built around an 8080 microporcessor. This peripheral handles much of the routine data acquisition and reduction and is expected to cut previously required measurement times approximately in half. As a check, selected data points are frequently taken then reduced both automatically and manually in order to verify the proper operation of the data handling system.

In this experiment, as in certain of our previous work,[25] a 6L6GC beam tetrode was used as an electron source. The tube envelope was first removed except for the base portion which supported the tube structure. One side of the plate was then opened to expose the grids and beam forming structure. A clamping fixture held the tube in position allowing the electron beam to exit from the beam forming structure, through several apertures, and into the interaction region. The source is capable of providing a 2.5 mm thick electron beam of 1 mA at 150 eV and more than 10 mA at 1000 eV. The mean energy of the electron beam is about 2 eV below that set by the acceleration voltage while the energy spread is about ±1 eV at half-maximum.

Considerable effort during this contract period was devoted to the development of a new type of ion gun. An aluminosilicate composite was mixed with molybdenum powder and pressed into a cylindrical plug. The resulting pellet was sintered and nickel brazed to a commercially available heater. This assembly was then mounted behind a specially designed, five-element, Pierce-type focusing structure, as shown in Figure A-3. This thermionic-type ion source produced a chemically pure beam of ground state alkali ions. No differential pumping or water cooling was required with this type of source. The ion source produced a uniform beam of 2-5 x 10^{-7}A for an operating period of several weeks. Impurity levels were always less than 0.5% of the desired ion emission current. This new ion source has considerably simplified ion beam handling and has enhanced the control over the beam interaction geometry.

The electron current was determined from the voltage drop across a precision resistance as monitored with a digital voltmeter. The error in the electron current determination was less than ±1%. The singly-charged-ion beam current was measured with a conventional electrometer while the multiply-charged-ion beam current was measured with a vibrating reed electrometer operating in the rate-of-charge mode. An integrating digital voltmeter connected to the vibrating reed electrometer supplemented a chart recorder

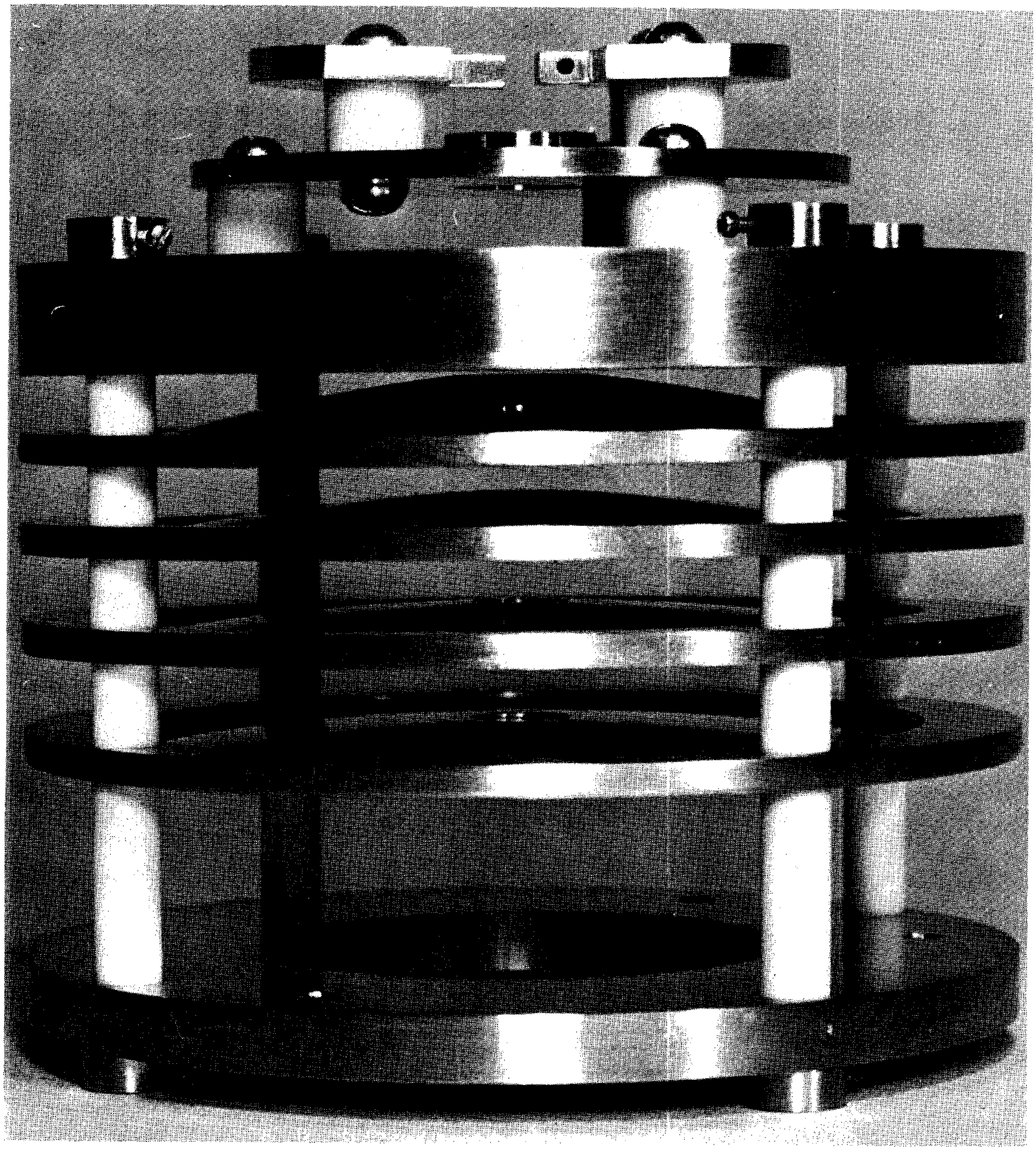

Figure A-3. Photograph of the Pierce-Type Ion Gun.

in data acquisition. The estimated error in the singly- and multiply-charged ion beam currents was less than ±2% and ±3%, respectively.

The experiment was operated in the pulsed beam mode.[30] This technique eliminated background gas density modulation effects which otherwise might occur for vacuum system pressures of greater than about 10^{-8} Torr. Both the ion beam and the electron beam were pulsed; the ion beam with a 35% duty factor and the ion beam with a 50% duty factor. By a simple change of the relative phases of the two beams, the ions and electrons could be made to cross the interaction region either in time-coincidence or in time-anti-coincidence. The difference between the coincidence and anti-coincidence signals represented the electron impact ionization current.

An absolute cross section for the triple and quadruple ionization of Rb^{+} ions obtained with the above apparatus are given in Figures A-4 and A-5. The data for each process were obtained from a single operating cycle of the experiment. Our usual procedure has been to consider data as preliminary until confirmed by at least two independent "runs" of the apparatus. The error bars include the sum of the random error and systematic errors. Random errors were estimated from the 90% confidence limits of the mean and the systematic error is taken to be ±4%; the uncertainty in the instrumentation calibration.

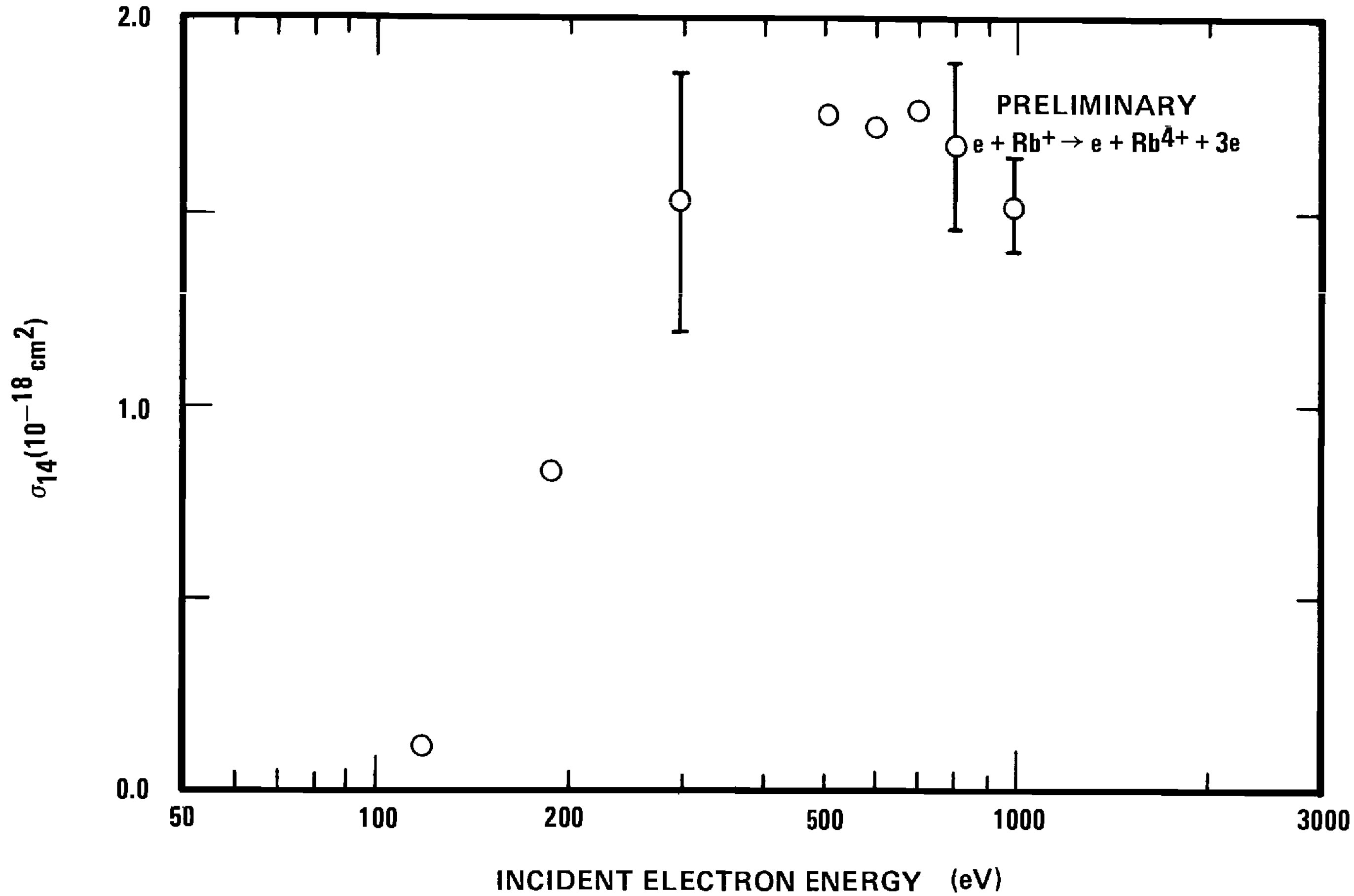

Figure A-4. Absolute Experimental Cross Sections for the Triple Ionization of Rb^+ Ions.

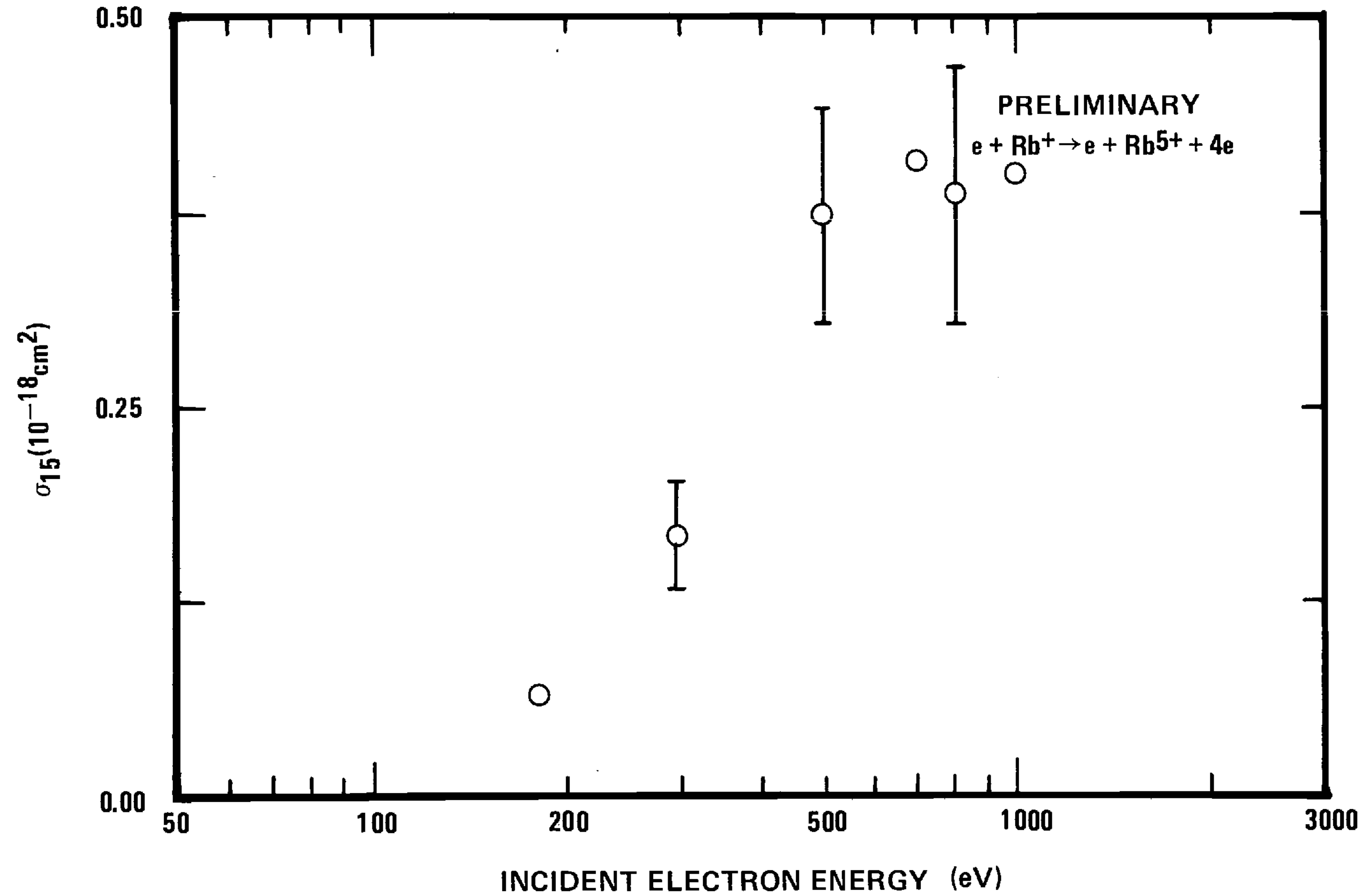

Figure A-5. Absolute Experimental Cross Sections for the Quadruple Ionization of Rb^{+} Ions.

APPENDIX II

IONIZATION OF METALLIC IONS

A major portion of the present effort is devoted to the development of a laboratory-size source of metallic ions. Such a source will then be used with the collision apparatus described in this and the previous Progress Report.[9] This appendix discusses the metal ion source and its associated beam handling system.

Effort during this contract period has concentrated on the selection and testing of an ion source to produce singly charged metallic species. A hollow cathode ion source originally developed by G. Sidenius of the Niels Bohr Institute was purchased from Danfysik/High Voltage Engineering. This ion source has been used extensively in high energy physics experiments and was thought to be readily adaptable to the needs of our ionization and charge exchange studies. An extractor-einzel-lens assembly was also commercially available at a cost of $4.8K. This amount was considered to be excessive and an equivalent assembly shown in Figure A-6 was designed and constructed for approximately 2% of the cost of commercial unit.

A photograph of the differentially pumped metal ion source appears in Figure A-7. The hollow cathode source was mounted on a stainless steel flange followed by a series of plexiglas spacers. This arrangement is mechanically sound and allows the ion source to be biased at potentials up to approximately 100 kV with respect to experimental ground. The entire assembly occupies one port of a cross-shaped vacuum chamber. Remaining orthogonal ports are used for pumping and electrical feedthroughs. An

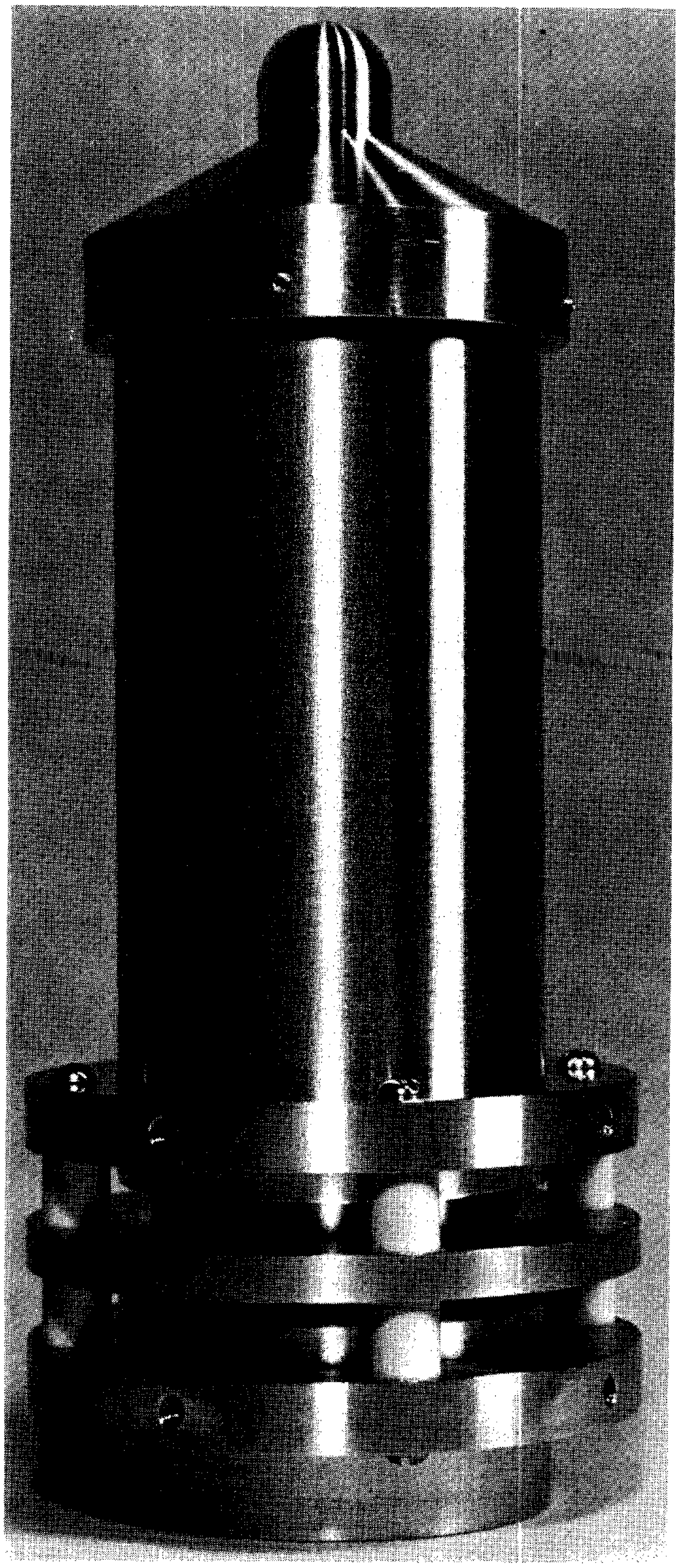

Figure A-6. Photograph of the Extractor-Einzel-Lens Assembly.

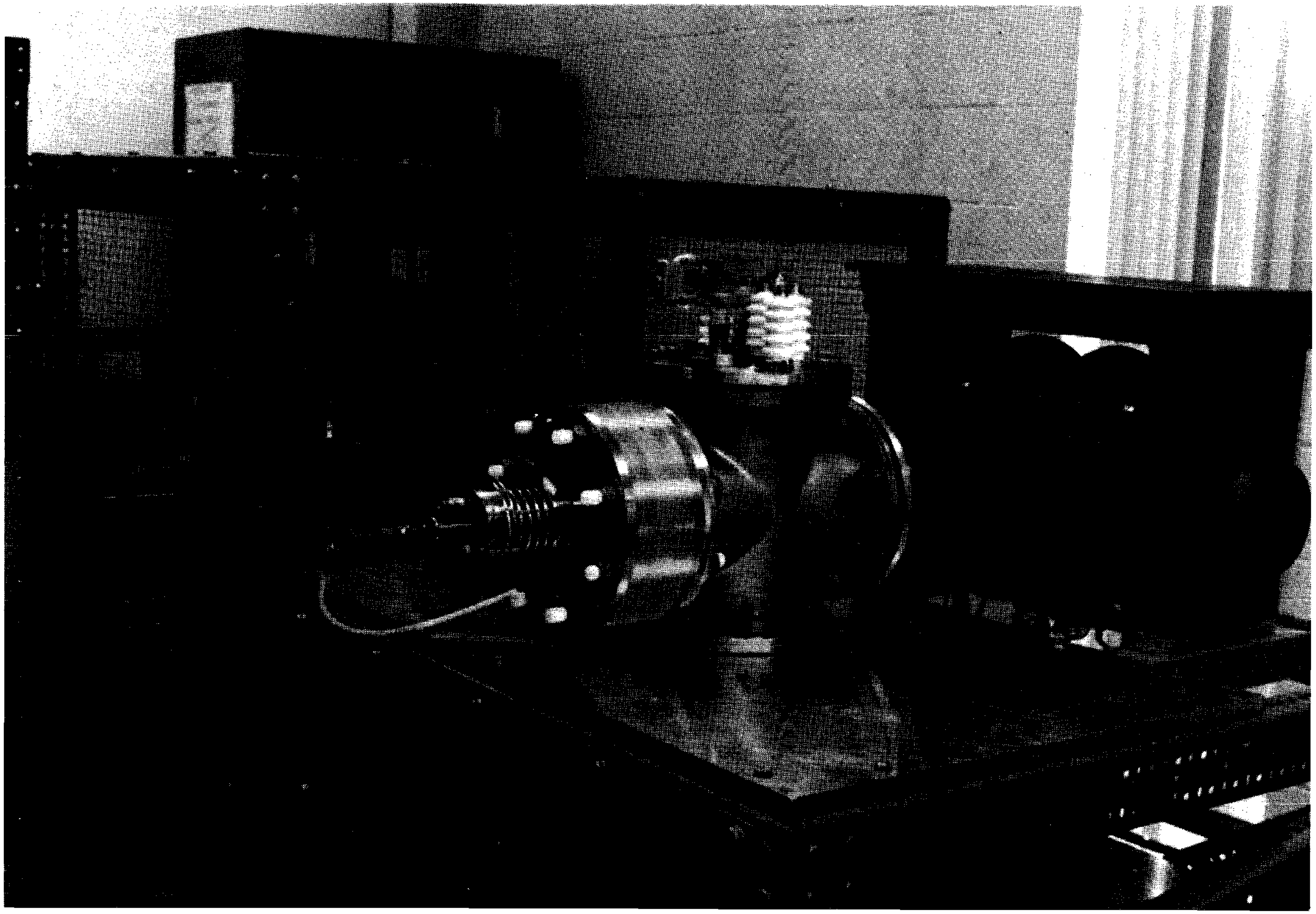

Figure A-7. Photograph of the Metal Ion Source Mounted on the Differentially Pumped Analyzer.

additional stage of differential pumping is provided by means of a four-inch, zeolite-trapped, oil diffusion pump. External to the final pumping stage is a Wien-type velocity analyzer to reject unwanted species while providing high throughput for the desired ions. This differentially pumped analyzer was designed with versatility in mind. Rolling tables and universal port heights allow the analyzer to be quickly interfaced with either the Danfysik metal ion source or the PIG-type ion source described in Appendix IV. The ion source-analyzer assembly then bolts to either the existing ionization experiment or to the charge exchange experiment presently under construction. Such an arrangement is extremely versatile and is expected to provide the basis for many future collision experiments.

Operation of the metal ion source requires power supplies for filament and oven current as well as power for an external compensation magnet. An additional medium voltage, high current supply is required to strike and maintain the arc discharge. Parts for all power supplies have been obtained and the necessary units have been constructed. A large isolation transformer has also been obtained to enable biasing of the above supplies at voltages up to 100 kV.

Recent tests of the metal ion sources have used argon as a source gas. Initial results indicate source pressures of approximately 5×10^{-5} Torr at arc currents of 2 A. Total Ar^+ ion beam currents are of the order of 10^{-6} A with 1000 volts extraction. Extraction of microamperes of 1000 eV. Au^+, Cu^+ and Ni^+ ions appears to be possible. Preliminary results with this hollow cathode source have been very encouraging and this unit is expected to generate the required singly-charged metal ions for all foreseeable collision studies.

APPENDIX III

ELECTRON STRIPPING AND CAPTURE CROSS SECTIONS

Electron capture and stripping cross sections of selected metallic impurity ions in H_2, He and N_2 gases are of paramount importance in the determination of the rate at which impurities produced in the neutral beam injection system enter the plasma confinement region. This appendix describes the hardware under construction to measure these cross sections over the range of ion energies from 5 to approximately 100 keV.

Effort during the present contract period has been devoted to the acquisition of appropriate vacuum hardware and a 130 kV power supply. A preliminary design for the charge exchange apparatus appears in Figure A-8. Ions from either the PIG- or the hollow-cathode-discharge-type ion source (both sources described elsewhere in this report) are accelerated to the desired energy and enter the neutralizer cell. Here some of the ions are neutralized by charge transfer. This cell is operated under thick target conditions for maximum neutral particle yield. The output of the neutralizer passes between a set of sweep plates which remove the charged particles from the beam. Differential pumping is used to keep the pressure in the flight tube to less than 10^{-6} Torr. The purified beam is then directed into the collision chamber. This chamber is usually operated under single collision (thin target) conditions. A Baratron capacitance manometer is used to measure the pressure in the collision region. Neutral atoms entering the collision chamber are stripped on the gas atoms. Stripping of several electrons in a single collision is possible, but the operating pressure is sufficiently low that multiple collisions are unlikely. The beam emerging from the collision chamber is analyzed for charge state composition with a

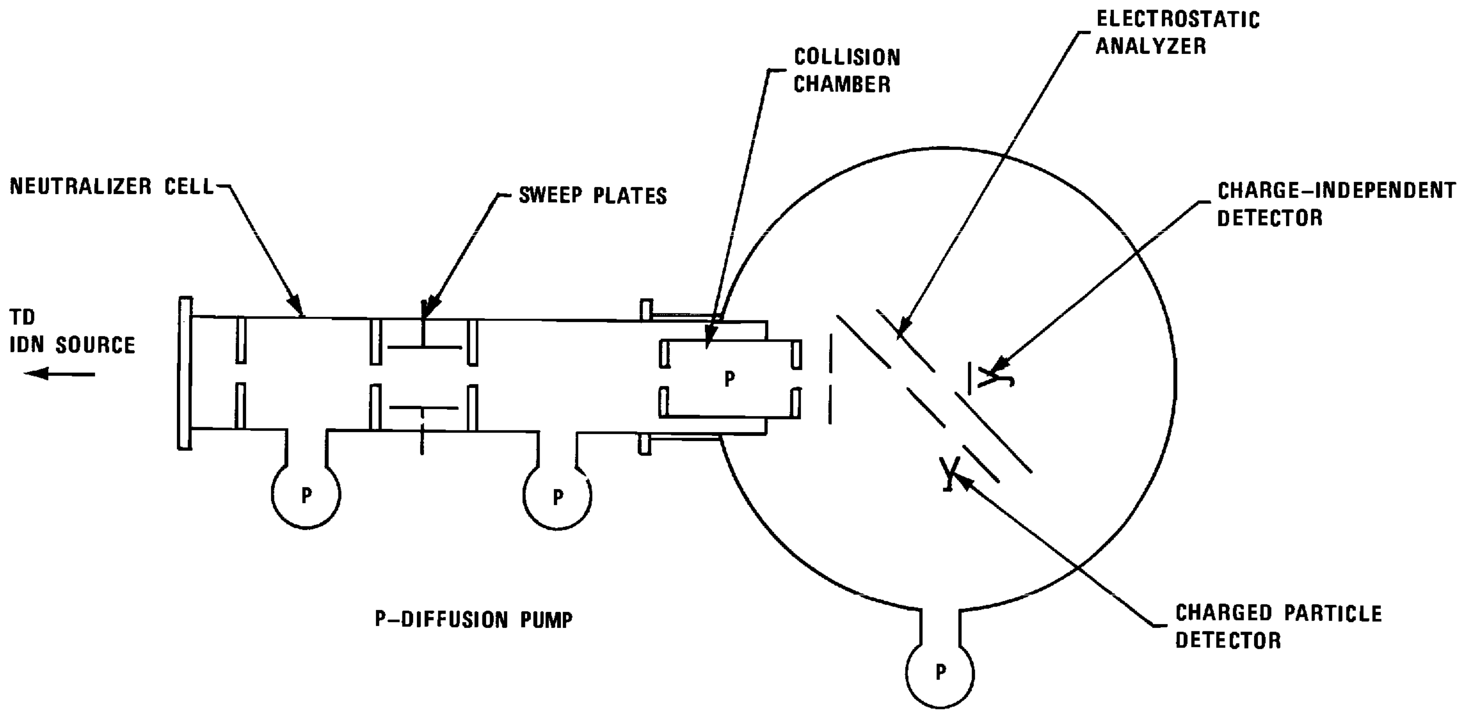

Figure A-8. Schematic Diagram of the Charge Exchange Experiment.

parallel plate electrostatic analyzer. The charged component is measured with a Faraday cup or with a funnel electron multiplier. A hole in the electrostatic analyzer allows passage of the neutral beam into a charge-independent detector. The entire detection system will be mounted on a movable assembly so that angular scattering of the particles may be studied.

Electron capture cross sections are measured in the same apparatus by pumping out the neutralizer cell and allowing the unperturbed ion beam to enter the collision chamber. The collision chamber is again operated under single collision conditions. Ions neutralized in the collisions are detected with the charge-independent detector while unneutralized ions are deflected by the electrostatic analyzer. Multiply stripped ions can also be identified by application of appropriate bias to the electrostatic analyzer.

APPENDIX IV

ION SOURCE DEVELOPMENT

A small portion of the present effort is devoted to the development of a laboratory-size ion source of multiply-charged ions. Such a source will then be used with an experimental apparatus, such as described in this and the previous Progress Report,[9] to measure ionization and charge exchange cross sections of multiply-charged ions. This appendix discusses the multiply-charged ion source and its associated beam handling system.

Efforts during initial contract periods concentrated on an evaluation of various sources as candidates for producing ions suitable for charged-particle--charged-particle crossed beam experiments. Ion source types considered included the washer-type pulsed plasma source, the trapped-ion source, various configurations of an electron-cyclotron source, the hot-electron plasma source, the duoplasmatron source, and the Penning Ion Gauge (PIG) source. Most of the plasma-type sources were very complicated and required extensive support facilities. The duoplasmatron was rejected because of its low yield of highly-charged ions. It was concluded that the PIG source presented fewest technological risks, and could be made a suitable size for use in the laboratory.

Final design, construction and testing of a suitable PIG-type ion source was completed during the previous contract period. A photograph of the PIG and associated support equipment appears in Figure A-9. A description of the experimental apparatus is given in a previous Progress Report[9] and will not be repeated here. Rather, the present discussion will

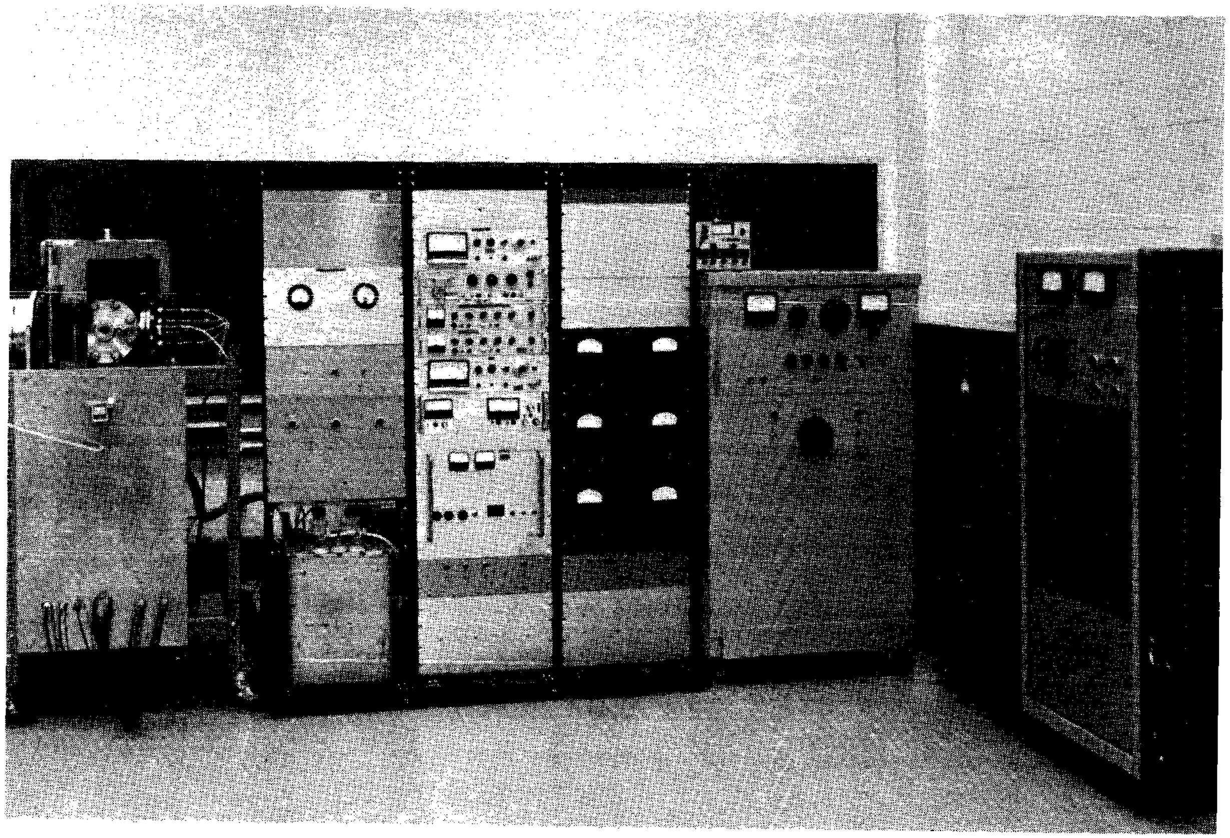

Figure A-9. Photograph of the PIG-Type Ion Source and Support Equipment.

be limited to specific problems regarding the application of this PIG-type ion source to future collision studies.

Under typical operating conditions, the PIG arc circuit draws 2-5 A at 500 V. At such operating powers the source appears to fail when the depth of an arc crater in a cathode is equal to the cathode diameter. For a cathode dissipation of 1.5 KW erosion of the magnitude is apparent after about 10 hours of operation. Several different cathode shapes have been tried in an attempt to find one which would simultaneously provide adequate ion yield and long cathode lifetime. Unfortunately these two requirements seem to be inversely related and thus frequent cathode replacement is necessary. Cathode replacement on the originally designed PIG-source was a difficult and time-consuming process. A new configuration for the cathode holders has been considered and a preliminary design is underway for a PIG whose geometry precludes this maintenance shortcoming.

Some difficulty has been experienced in extracting significant numbers of highly charged ions from the Penning discharge. In general, the extraction of ions from a plasma by electrostatic means is a complex and poorly understood phenomenon.[31] Plasma in proximity to extraction and deflection plates encourages electrical breakdown between these components and the positively biased anode. A preliminary design is presently underway for an anode-extraction combination less handicapped by this difficulty. The new geometry will use a heavily biased, rectangular extraction aperture physically removed from the plasma leakage region. Such a design will also allow the PIG source magnet itself to perform some m/e selection and is expected to significantly enhance multiply-charged ion yield.

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